COMBINED LINEAR-LOGARITHMIC IMAGE SENSOR

Field of the Invention

[0001] The present invention relates to electronics, and in particular, to a solid-state image sensor.

Background of the Invention

[0002] Dynamic range is a very important parameter of any imaging system. Human vision has the capability to see details across a wide illumination range in a single scene, and is reported to exhibit around 200dB of dynamic range. Scenes in excess of 100dB are not uncommon in everyday situations. Consequently, designers of image sensors are continuously looking for ways to increase dynamic range.

[0003] In the field of CMOS image sensors, sensors having a log characteristic are used for image scenes having a high dynamic range. In a logarithmic mode the pixel voltage is continuously available to the outside world and no integration time is used. The photocurrent that is induced flows through one or more MOS transistors and sets up a gate-source voltage that is proportional to the logarithm of the photocurrent. This is exemplified in Figure 1 where the gate-source voltage appears across M2. Since the photocurrent is very small, the MOS device(s) will operate in a sub-

threshold, and thus the voltage varies logarithmically with the photocurrent. The voltage is read out by source follower circuitry. Around six decades of light can be captured in the logarithmic mode.

[0004] Due to the small devices used in the pixels, a high degree of mismatch results from process variations, which produces fixed pattern noise (FPN) across the array. Logarithmic sensors cannot use double sampling (in its conventional form) for removing mismatch since this technique only removes the variation of device M1 and does not alter the effect of device M2.

[0005] Another disadvantage of the logarithmic arrangement is a slow response time for low light levels. Increased photocurrent for a given light level can be accomplished by increasing the size of the light sensing element, but this is not desirable since the cost for a given resolution will increase accordingly.

[0006] The prior art discloses designs intended to combine features of linear and logarithmic responses, for example, U.S. Patent No. 6,323,479 to Hynecek et al., and the article to Tu et al. titled "CMOS Active Pixel Sensor with Combined Linear and Logarithmic Mode Operation", IEEE Canada conference on Electrical and Computer Engineering 1998, vol. 2, pp 754-757, 1998. However, these prior art proposals do not address the FPN and slow response problems.

Summary of the Invention

[0007] In view of the foregoing background, an object of the present invention is to provide an image sensor that overcomes or mitigates the problems of linear and logarithmic sensors.

[0008] The invention, which is defined in claims 1 and 8, is based upon combining conventional integrating mode with logarithmic mode.

Brief Description of the Drawings

[0009] An embodiment of the invention will now be described, by way of example only, with reference to the drawings, in which:

[00010] Figure 1 is a schematic diagram of a pixel in an image sensor according to the prior art;

[00011] Figure 2 is a schematic diagram of a pixel in an image sensor forming an example according to the invention;

[00012] Figure 3 illustrates operation of the pixel as shown in Figure 2 in a logarithmic mode;

[00013] Figure 4 is a block diagram of one form of circuitry used in a readout chain according to the invention; and

[00014] Figure 5 illustrates voltage values used in the circuit as shown in Figure 4.

Detailed Description of the Preferred Embodiments

[00015] The basis of the invention is to combine a conventional integrating mode with a logarithmic mode. A single frame of image data will have the information for some pixels gathered from the integrating mode and other pixels from the logarithmic mode. The pixels that have saturated during exposure will have a log value (scaled appropriately). This keeps the superior performance of the integrating mode in low light conditions, but adds the high dynamic range of the logarithmic mode.

[00016] The combined linear-log system can be used

without the need for a framestore. After a period of integration the linear result is read before switching the pixel to the logarithmic mode and reading the log result. The log result is read in a near instantaneous manner, that is, as soon as the log signal has settled and while no other pixel is being addressed. The linear and log results are then combined during the readout phase.

[00017] The logarithmic mode can suffer from image lag due to its slow response time, but by using the linear mode for low light levels the present invention in the logarithmic mode only has to process higher photocurrents. Optionally, the addition of an amplifier connected to the pixel will further aid the response time in the logarithmic mode.

[00018] Referring to Figure 2, there is shown a single pixel of an image sensor forming one example of the invention. The pixel comprises a photodiode P connected between earth (ground) and a node pix when device M5 is on.

[00019] For linear operation the reset voltage Vrt (set in col4) can be sampled onto the node pix by pulsing cal/reset high and logsel can be raised to precharge the gate of transistor M2 via col3 low such that it is off and does not affect the integration period. If isolate is on then the photocurrent generated will lower the voltage on pix. After a set integration time read can be turned on such that M1 now acts as a source follower, with column 2 held at a voltage approximately equal to the reset voltage Vrt and column 1 comprising a current source (not shown).

[00020] Optionally, the pixel can include an anti-bloom arrangement to prevent blooming. Blooming is

caused by the node pix being driven to near zero volts, allowing leakage of current to adjacent pixels. The anti-bloom arrangement of Figure 2 comprises a transistor M7 which operates to clamp the photodiode voltage if it falls to some arbitrary low value set by ($Vb - Vth_7$), where Vth_7 is the threshold voltage of device M7.

[00021] The pixel is operated in the logarithmic mode by connecting an amplifier A from the column as shown in Figure 3. The transistor M1 of Figure 2 forms the inverting input of the amplifier A. The non-inverting input is held at a reference voltage Vref, and thus the node pix will sit at a level given by:

$$Vpix = Vref + Voff \qquad (1)$$

where Voff is the offset of the amplifier A. The output voltage is thus given by:

$$Vout = Vpix + Vgs(M2) \qquad (2)$$

where Vgs(M2) is the gate-source voltage of device M2 which is determined by the photocurrent and has a logarithmic dependence.

[00022] The offset of the amplifier can be removed by performing calibration, that is, by bringing the pixels into a reference state so that the FPN can be learned and cancelled. To do this, the photodiode P is isolated from the load device M2 by turning off device M5. This stops the photocurrent from corrupting the calibration. One method of generating a calibration current for device M2 is to use M4 as a switch to an in-column current source C. This allows a matched

current to be pulled through the load device of each pixel, and places each pixel into a reference state which should be equivalent to illuminating the sensor with a uniform intensity.

[00023] Other methods of calibration could be used, for example, those shown in Kavadias et al., IEEE Journal of Solid-State Circuits, vol. 35, No. 8, August 2000 and in Loose et al., *ibid.*, vol. 36, No. 4, April 2001, may be used.

[00024] Referring to Figure 4, one suitable readout scheme for selecting between linear and logarithmic outputs is shown. The linear and log signals for each given pixel are read out sequentially. The linear signal and the corresponding dark reference signal are applied to a difference circuit 40, and the difference is converted to digital format by analog-to-digital converter 42. The log signal and the log calibration signal are applied to a difference circuit 44, and the difference is converted to a digital format by analog-to-digital converter 46. The two digital signals are applied to a logic circuit 48 that passes the linear or the log signal based upon whether or not the linear signal is saturated.

[00025] However, where a log output is used the actual output must include an offset to place it correctly into the linear range. Referring to Figure 5, the log offset is computed to be a value A by comparing a non-saturated linear value with a log value with a log value and taking the difference. All linear values greater than A are then taken to be saturated or near saturation, and are replaced by log values to which the offset A is added.

[00026] The calculation of A can be done once, and

need only be changed if the exposure time is altered. Thus, the present invention combines features of linear and logarithmic sensors in a manner that avoids or minimizes the drawbacks of both types.